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Optimizing Growth Options for the Wewahootee Pump and Transport System

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OPTIMIZING GROWTH OPTIONS FOR
THE WEWAHOOTEE PUMP AND TRANSPORT SYSTEM

BY

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ABSTRACT

Techniques for performance optimization and energy reduction were reviewed for application to water supply plants. Simple techniques were developed which permit intelligent management decisions for plant operation and growth. The techniques were applied to the Wewahootee Water Supply Plant, Cocoa, Florida. Optimum performance for the existing plant was determined together with a growth plan for reducing energy consumption and increasing the maximum flow capacity to meet demand through the year 2000.

The following recommendations were made:

1. Plant operators should incorporate the optimized pump operation schedule presented herein.

2. Four existing pumps should be modified for dual speed operation, and a large capacity dual speed pump should be added.

3. One 10,400 foot section should be added to the 42-inch pipe by 1985 and a second section by 1990.

4. An economic analysis should be performed to determine if it is advantageous to accelerate installation of the 42-inch pipe.

5. The use of stored water should be considered to smooth the flow demands placed on the pumps.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Carl R. Larrabee, P.E. for his suggestion of the project and for providing basic data without which the project would have been impossible.

Special thanks are due to Howard Mahoney and the staff at SOC for their willingness to accommodate the author's varied schedule. Without their support, completion of this Master's program would have been impossible.

Finally, recognition is due to Dr. J.P. Hartman who, because of his superior approach to teaching, has set an example for others to follow.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

The Wewahootee Water Supply Plant is an aeration, storage, and pumping facility which supplies fresh water for all of central Brevard County including Kennedy Space Center and the beaches. Raw water is collected from 18 active wells and is passed through seven aerators. Two additional wells and one additional aerator are under construction. Aerated water is stored in four ground storage tanks which have a combined volume of 2.5 million gallons. The ground storage tanks are interconnected and supply water to five high service pumps. The water is transported approximately nine miles via concrete pipe to the Dyal Water Treatment Plant, a water softening facility.

The five high service pumps have a maximum capacity of 33.3 MGD to the Dyal Plant. There are three flow modes from Wewahootee: gravity flow (0 to 13 MGD), intermediate flow requiring throttling of excess head (13 to 31 MGD), and high flow (31 to 33 MGD).

When Wewahootee was constructed in 1954, the Dyal Water Treatment Plant did not exist, nor was it planned. The pumps were sized to transport water to the City of Cocoa, a distance of approximately 17 miles. Later, when Kennedy Space Center came to the county, a requirement for soft water was generated; thus the Dyal Treatment Plant was built, and the transport distance decreased to nine miles. Consequently the pumps were oversized for the job (excess head).

The interim solution was to provide additional resistance at the Dyal Plant in the form of throttling so that the pumps could operate within their design range.

The water demand has been estimated based on population growth and is shown below (Larrabee, 1982). The data indicate that the maximum daily flow capacity should be increased to approximately 45 MGD by the year 2000.

WATER DEMAND PROJECTIONS - CITY OF COCOA WATER SYSTEM

	Daily Flow Rate (MGD)		
Year	Minimum	Average	Maximum
1982-1985	9.5	18.5	32.5
1986-1990	11.5	20.5	36.5
1991-1995	13.5	22.5	40.5
1996-2000	15.5	24.7	44.5

With this background, the following objectives were established for this study: (a) optimize performance of the existing system to minimize power consumption, (b) investigate modifications to reduce power wastage, (c) investigate modifications to increase maximum flow capacity to satisfy demand through the year 2000.

Existing System

The pump system at Wewahootee consists of five high service, centrifugal pumps operating in parallel. The pumps are driven by constant speed electric motors and are operated remotely from the

Dyal Plant. There are three different pumps (designated 1, 2, and 3) with two each of pump No. 2 (designated 2A and 2B) and two each of pump No. 3 (designated 3A and 3B). Pump performance data are shown in Figures 1, 2, and 3. A sixth pump installation exists, however a motor is required for the pump to be operational. The pump is a duplicate of No. 1 and is designated 1B in this report.

Pumps 1A, 2A, and 2B have remotely operated control valves while pumps 3A and 3B have check valves so that any combination of pumps can be operated at a given time. This provides maximum flexibility of operation to satisfy the varying demand. Performance for a typical combination of pumps is shown in Figure 4.

The suction line from the ground storage tanks is a 24-inch diameter pipe which can transport flows of 45 MGD with acceptable head loss. A schematic of the supply system is shown in Figure 5. Operating practices require that the storage tanks be kept at least half full, thus assuring a minimum NPSH of 20 feet at the pump inlets. Calculations of suction head loss and NPSH are shown in Examples 1 and 2 of the appendix.

The pump discharge is transported to the Dyal Plant via 44,123 feet of 36-inch diameter reinforced concrete pipe. This section is paralleled with 8700 feet of 42-inch diameter pipe. The 36-inch pipe feeds 2400 feet of 54-inch diameter pipe. A schematic of the transport system is shown in Figure 6.

A head-flow curve for the existing transport system is shown in Figure 7. The elevation difference between the ground storage tanks (when half full) and the Dyal Plant receiving basins is approximately 30 feet. This head will produce a gravity flow of 13 MGD when the pipeline is properly maintained.

A vertical standpipe located near the pump discharge will overflow when the system pressure exceeds 150 feet (65 psi gage). Thus, pump performance is bounded at one extreme by the 150-foot head limitation. Pump performance is limited at the other extreme by the available NPSH. The performance limits for pump 1 are illustrated in Figure 1.

Existing system performance is shown in Figure 8 for selected combinations of pumps (the A and B designators have been deleted). At intermediate flow rates, the minimum pump head is limited by the available NPSH. In order that the pumps not cavitate, additional resistance must be provided in the form of throttling. For instance, if pumps 1A, 2A, and 2B are used to deliver 20 MGD, then 87 feet of head or approximately 420 HP must be wasted. If pumps 2A, 2B and 3A (or 3B) are used to deliver 20 MGD, then 110 feet of head or 525 HP must be wasted. At $.06 per kilowatt-hour (1982 costs), 1 HP costs approximately $1 per day. Thus, to pump 20 MGD, $420 to $525 are wasted each day. Power wastage and power cost calculations are shown in Examples 3 and 4 of the appendix.

Optimization of Existing System

Techniques were reviewed to optimize performance of the existing system to minimize power consumption. Mathematical optimization techniques are discussed by Bellman (1963), optimal control by Leitmann (1966), and optimal estimation by Gelb (1974). However, the problem of multiple pumps with nonlinear performance curves and multiple boundary conditions is formidable. Few would attempt the solution; and if a solution were obtained, the result would require considerable interpretation to be understood. Stark and Nicholls (1972) suggest that in some cases graphical optimization techniques are superior from a practical point of view. That was found to be the case for this application.

Howard (1980) attempted to determine the most efficient pump combination from the system performance curve. This technique is adequate for the trivial case; i.e., when only one combination of pumps will provide the desired flow rate. When several combinations of pumps are available, a better technique is needed.

The approach developed here requires that the operational flow range and power requirement be determined for each pump combination without regard to the system resistance curve. The data are then plotted graphically to show power required versus flow rate. If desired, the system operating point can be shown on the proper curve for each pump combination. The combination requiring the least power for a given flow rate can then be determined by inspection.

The operational flow range and power consumption is shown in Table 1 for each combination of pumps. The data are presented graphically in Figure 9 to show power required versus flow rate. From this data the combination of pumps which requires the least power can be selected. For instance, four different combinations of pumps will deliver 23 MGD; but the combination of 2A, 2B and 3A (or 3B) requires the least power. Utilization of this information will permit power consumption to be minimized for the existing system. For intermediate flow rates, the desired operating point lies to the extreme right of pump flow range (NPSH limited). If a straight line is drawn through the extreme right operating points, the slope is found to be approximately 26.7 HP/MGD. This represents optimum performance for the existing system. Unfortunately, the optimum leaves a great deal to be desired.

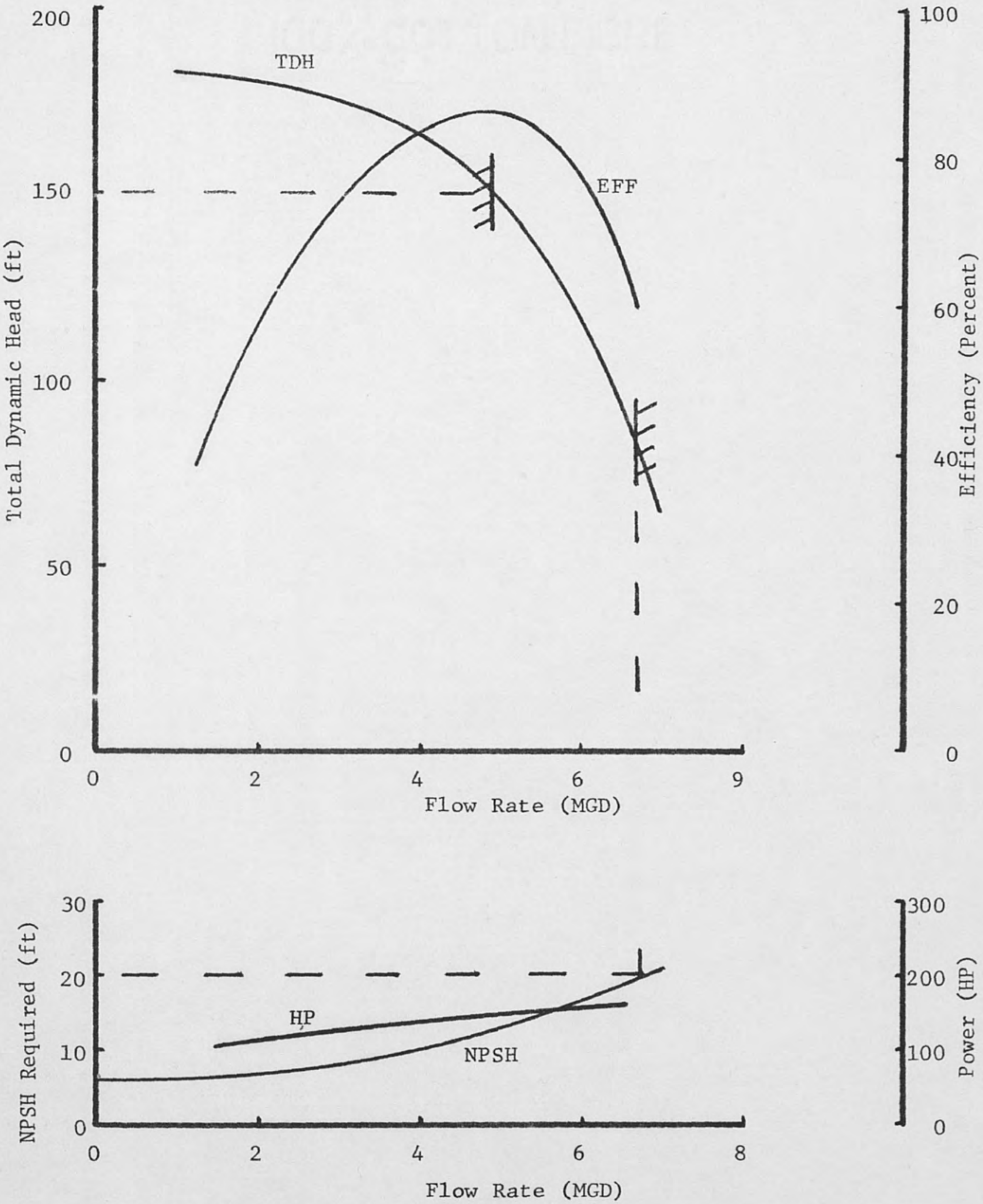

Fig. 1. Pump No. 1 performance - 1750 RPM.

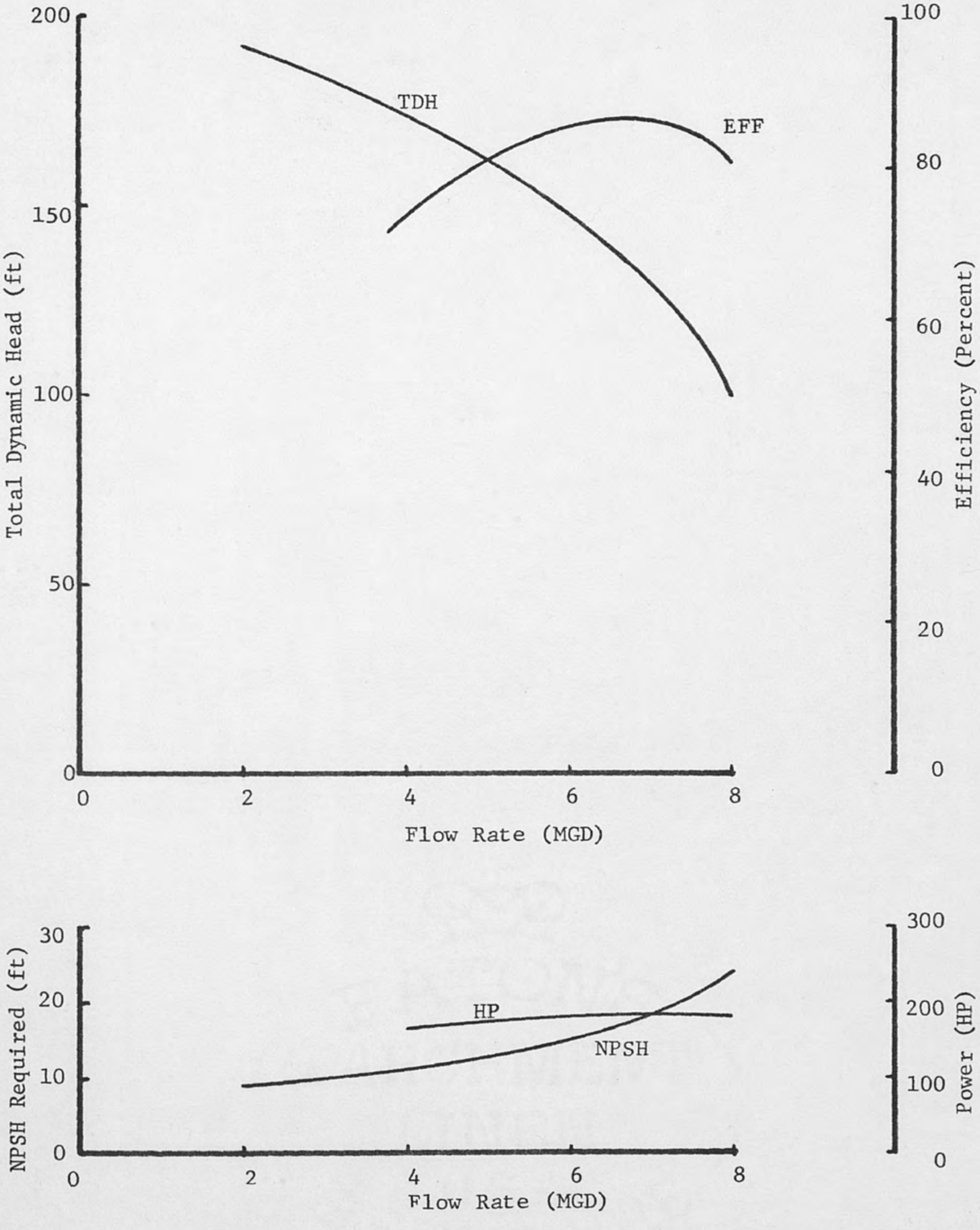

Fig. 2. Pump No. 2 performance - 1750 RPM.

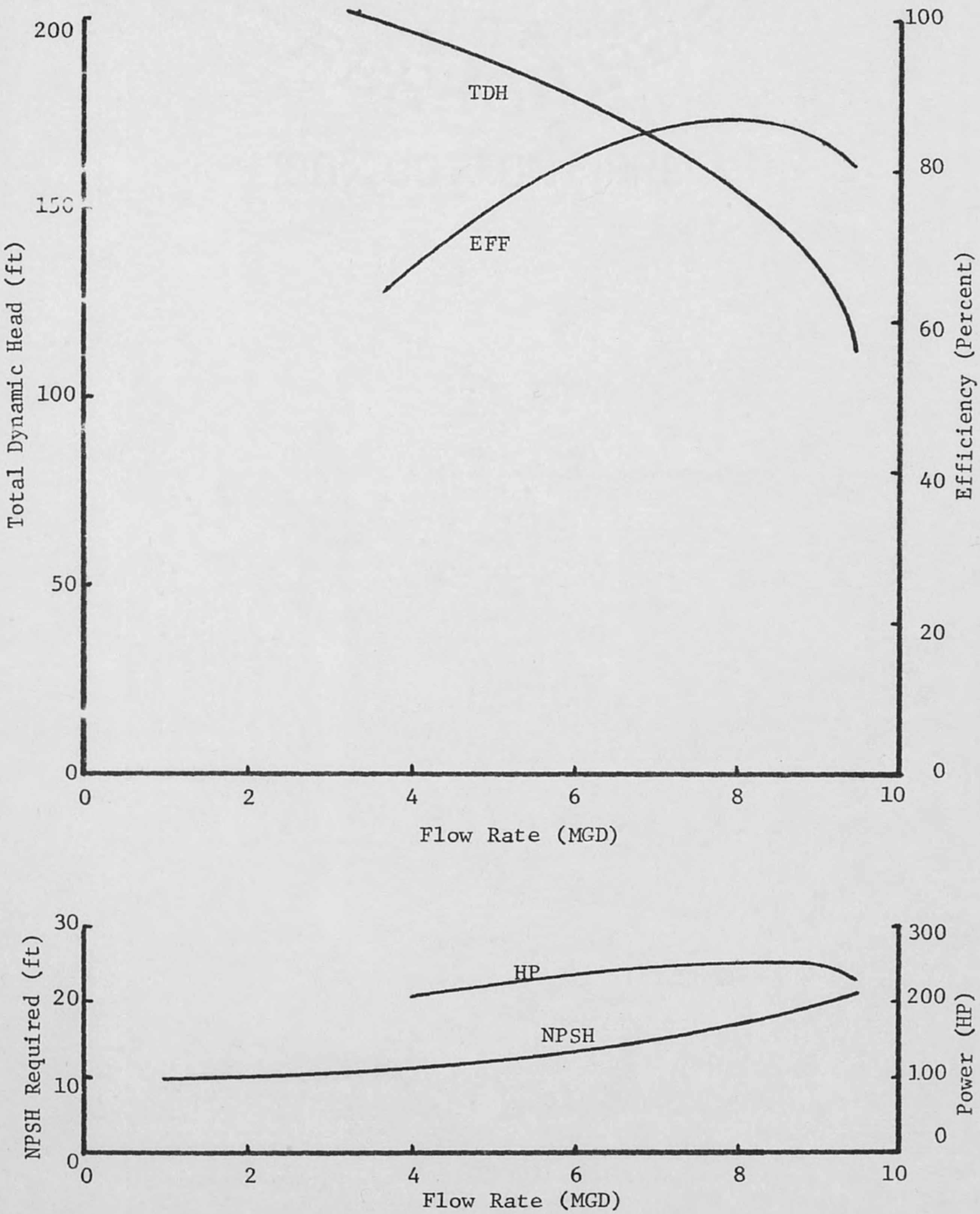

Fig. 3. Pump No. 3 performance - 1750 RPM.

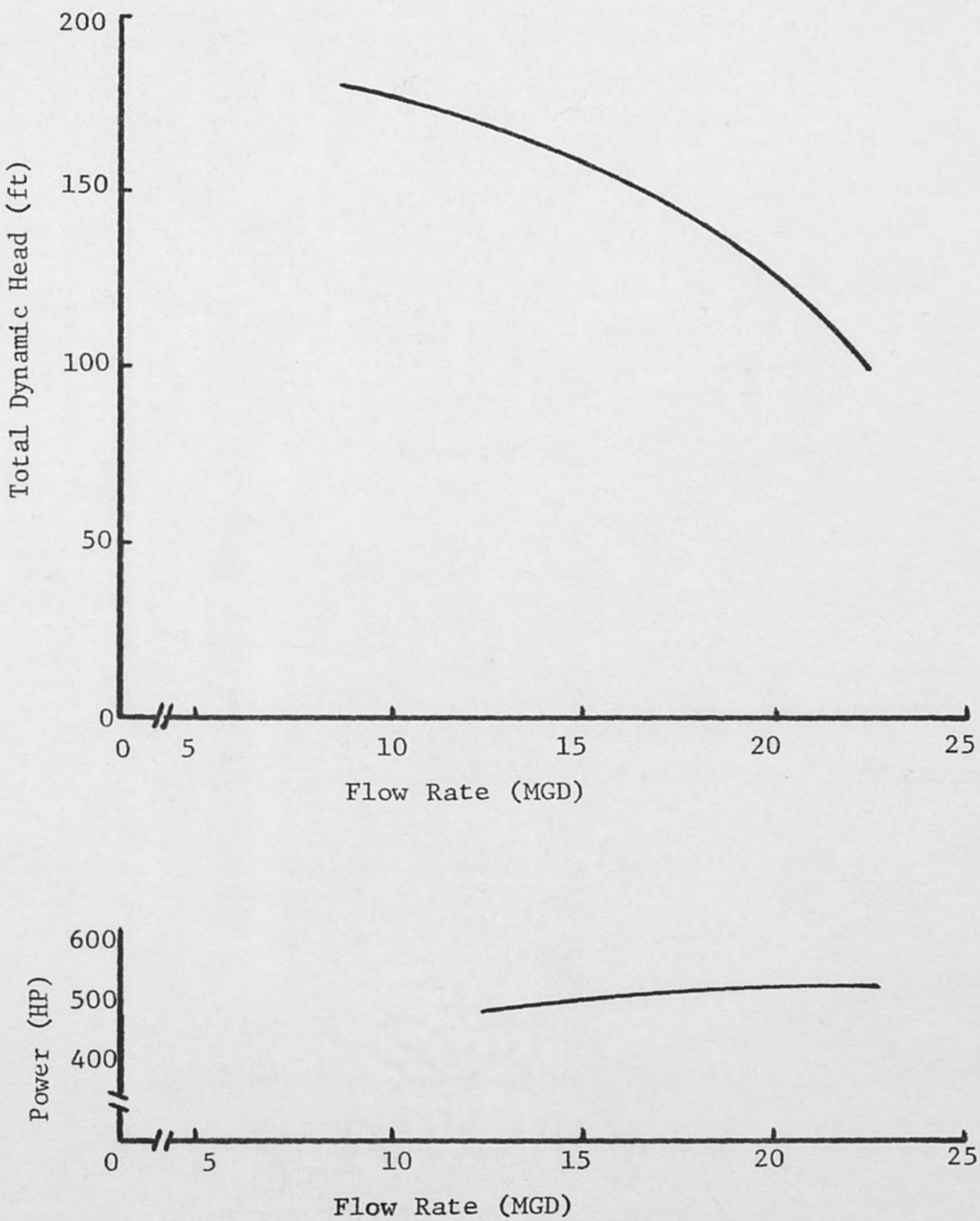

Fig. 4. Pump 1A, 2A, 2B performance - 1750 RPM.

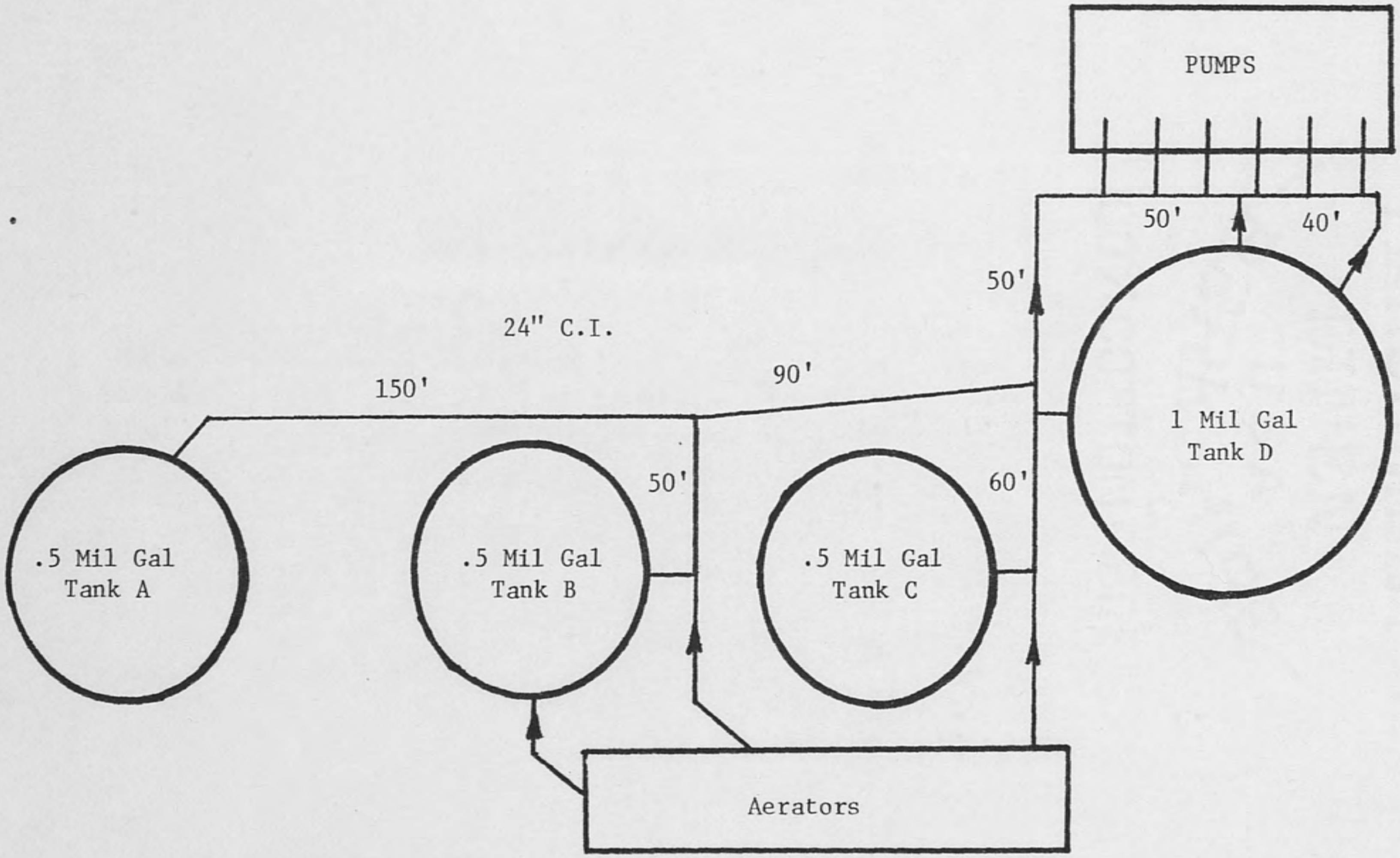

Fig. 5. Supply system.

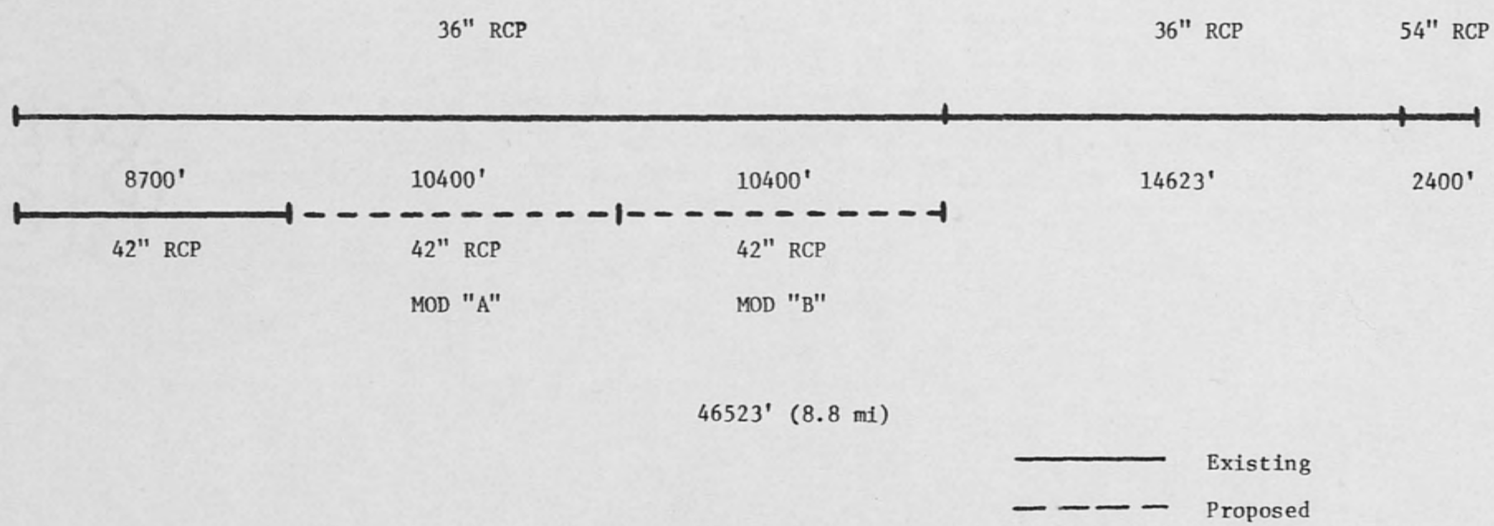

Fig. 6. Transport system.

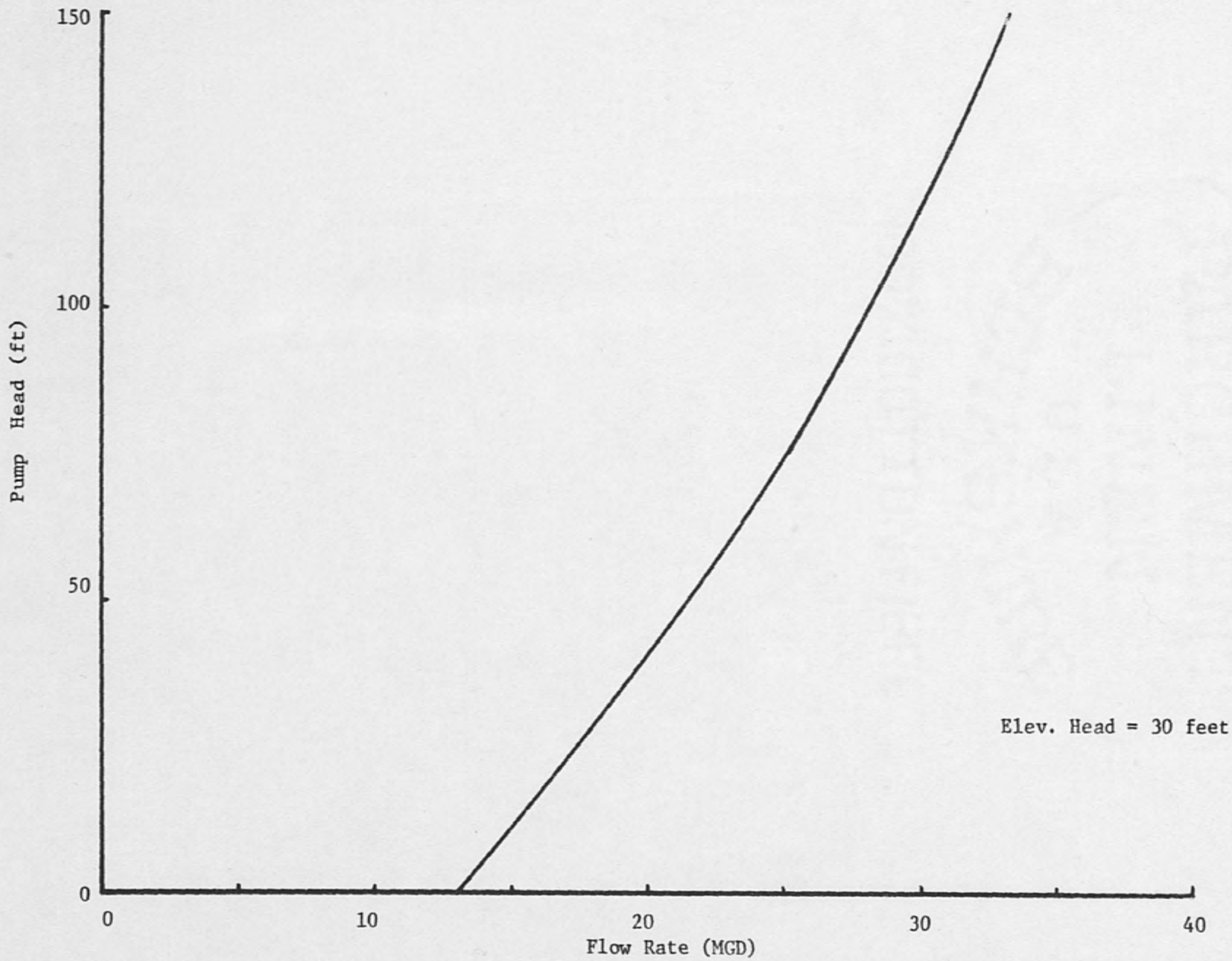

Fig. 7. Head vs. flow existing system.

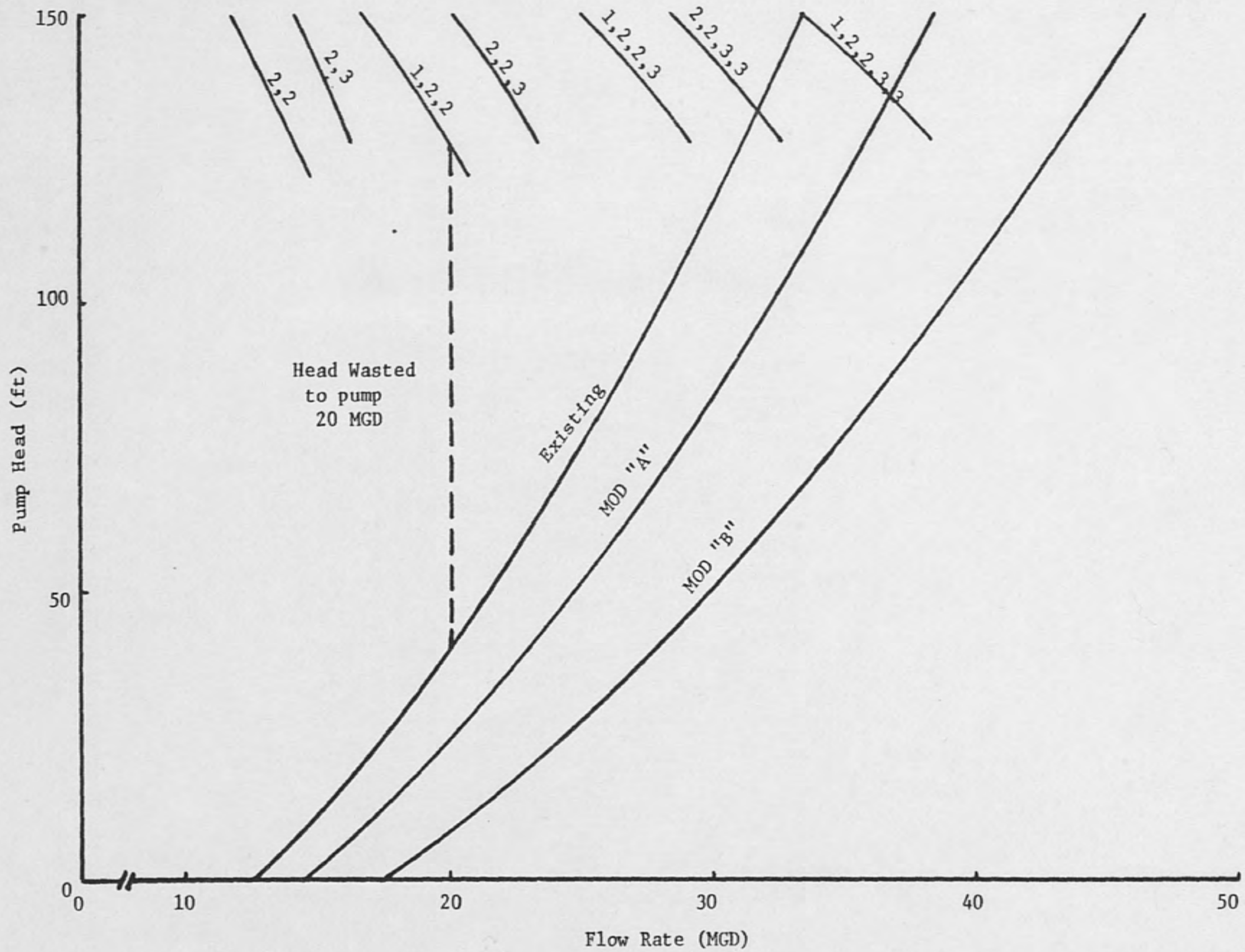

Fig. 8. System performance - existing.

TABLE 1

PUMP CAPABILITY
Existing

Pumps	Flow Rate (MGD)		Power (HP)	
	Min	Max	Min	Max
1	4.9	6.8	150	165
2	5.9	7.4	180	185
3	8.3	9.2	250	245
1,2	10.8	13.3	330	345
1,3	13.2	14.9	400	400
2,2	11.8	14.8	360	370
2,3	14.2	16.3	430	430
3,3	16.6	18.4	500	490
1,2,2	16.7	20.7	510	530
1,2,3	19.1	22.0	580	585
1,3,3	21.5	24.1	650	645
2,2,3	20.1	23.4	610	615
2,3,3	22.5	25.5	680	675
1,2,2,3	25.0	29.1	760	770
1,2,3,3	27.4	31.2	830	830
2,2,3,3	28.4	32.6	860	860
1,2,2,3,3	33.3	38.3	1010	1015

Min. flow: Discharge head = 150 ft
Max. flow: NPSH required = 20 ft

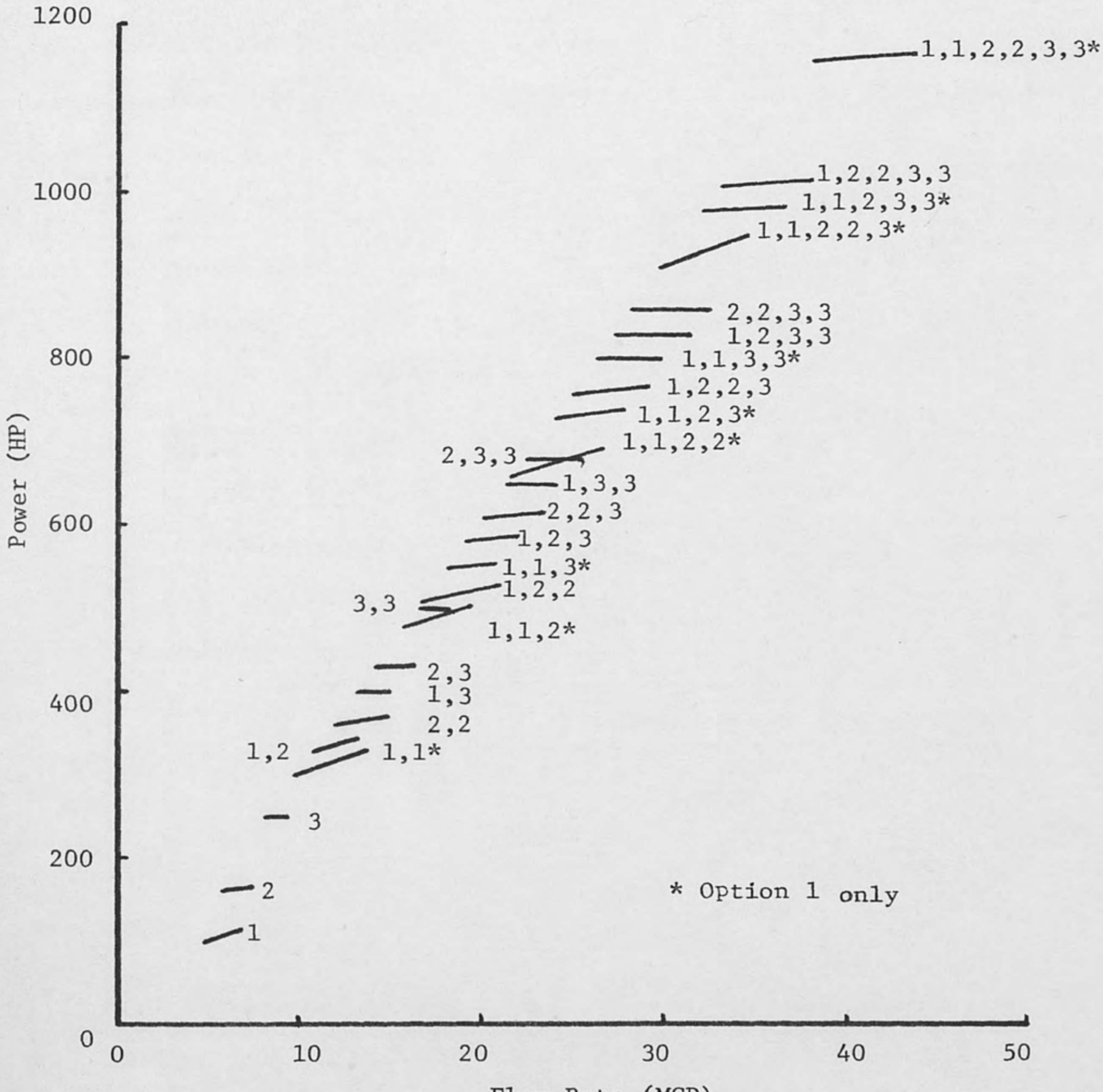

Fig. 9. Power requirements - existing and option 1.

ENERGY REDUCTION AND GROWTH OPTIONS

Energy reduction techniques were investigated for application to Wewahootee. Price (1980) indicated the importance of matching pump performance to the actual operating condition. Gottliebson (1977) discused the advantages of variable speed pumps. Pearson (1980) discussed the importance of minimizing the pumping head. He also stressed the importance of efficient motors and other mechanical equipment. Deb (1980) developed a model to determine the pipe diameter which would have the least cost for a given installation. Landes (1980) related that system resistance curves could be lowered by cleaning with a foam pig. Repetto (1980) proposed a correlation matrix to evaluate the effect of independent variables.

Other techniques considered briefly included: (a) addition of a turbine-generator to utilize excess head, and (b) addition of solar energy generating devices. Both were seen as treating the symptom rather than the cause and were not considered further. Pipe cleaning is accomplished at Wewahootee by periodic doses of chlorine; therefore there is little room for improvement in that area.

The obvious choice for energy reduction is the pumps; i.e., reducing pump head to match the system resistance curve. To capitalize on existing equipment, two speed pumps were chosen for further study. As pump speed is reduced, the head is reduced by the square of the speed ratio while the flow is reduced in proportion to the the speed ratio. And when the number of on-line pumps is varied to meet the system demand, many of the advantages of variable speed pumping can be achieved.

The transport pipe was the next obvious choice for energy reduction and growth. Pipe diameter was selected to be compatible with existing hardware; however length was varied for different options.

With all of the options to be considered, a management tool was needed to provide quick insight and rapid performance comparison. A matrix presentation was selected to accomplish this objective.

Two growth options were considered for the transport pipe. Each consisted of an addition of 10,400 feet of 42-inch diameter pipe in parallel with the existing 36-inch pipe. The growth options are shown in Figure 6 and were termed Mod "A" and Mod "B" Each 10,400-foot section would cost approximately $800,000 installed.

Three options for improving pump performance were considered: (1) addition of pump 1B (cost $2,000); (2) addition of pump 1B and dual speed capability for pumps 2 and 3 (cost $52,000); and (3) addition of a large capacity dual speed pump and dual speed capability for pumps 2 and 3 (cost $170,000).

The proposed modifications to the transport pipe and the pumps formed a matrix of growth options. Performance data were generated for each of the options and were evaluated for system performance.

Transport Pipe

The Hazen-Williams pipe flow equation was used to generate a model of the existing system which could then be used to predict performance for the modified system (Mod "A" and Mod "B"). The basic equation for a simple pipe segment was expanded to represent the complex system shown in Figure 6. See Table 2 for details. The L* for the existing system was computed to be 1397.1 feet. A value for C equal to 118.6 was found to provide an excellent match to the head-flow curve shown in Figure 7. This was reasonable since Morris and Wiggert (1972) suggest values of C ranging from 100 to 140.

The L* for Mod "A" and Mod "B" were found to be 1079.4 feet and 761.7 feet respectively. The head-flow curves were computed for Mod "A" and Mod "B" and are shown in Figure 8.

Existing Pumps And Modified Pipe

Figure 8 shows system performance with the existing pumps and the modified pipeline. The maximum flow rate was increased to 36.7 MGD for Mod "A" and 38.3 MGD for Mod "B." Gravity flow rates were also increased to 14.6 MGD and 17.6 MGD, respectively. However, no benefits were derived in the intermediate flow range.

Option 1

For option 1, a motor would be added to pump 1B so that it could be made operational. This option cost $2000 and represented the smallest capital investment.

System performance is shown in Figure 10. It can be seen that no performance benefits were realized with the existing pipeline; however, some operational benefits could be derived due to additional flexibility. Maximum flow rate was increased to 38.3 MGD for Mod "A" and 43.6 MGD for Mod "B"; however, no benefits were derived in the intermediate flow range.

Operational flow range and power consumption are shown in Table 3 for each combination of pumps. The data are shown graphically in Figure 9 and indicate little improvement over the existing pump system.

Option 2

For option 2, pump 1B would be added (cost $2,000) and pumps 2A, 2B,3A, and 3B would be modified to have dual speed capability (cost $50,000). This would be accomplished by installing double drive shafts, centrifugal clutches, and constant speed 1150 RPM electric motors. Performance for pumps 2 and 3 is shown in Figures 11 and 12 respectively for low speed operation.

System performance is shown in Figure 13. It can be seen that system efficiency for the intermediate flow ranges was dramatically improved. The data indicated that 20 MGD could be pumped at an expense of 190 HP (low speed) versus 530 HP (high speed). Based on the potential savings in operating costs, it appears that dual speed operation should be implemented as soon as possible.

Low speed pump operation was found to provide maximum flow rates of 22.4 MGD with the existing pipeline, 24.8 MGD for Mod "A" and 28.1 MGD for Mod "B."

The operational flow range and power consumption for low speed pump operation are shown in Table 4; high speed data are shown in Table 3.

Option 3

For option 3, a new large capacity dual speed pump, designated pump 4, would be added at a cost of $120,000. Pump performance is shown in Figures 14 and 15 for low and high speed operation, respectively. Pumps 2A, 2B, 3A, and 3B would be modified to have dual speed operation as in option 2 at a cost of $50,000. Pump 1B would be removed and pump 4 mounted in its place.

System performance is shown in Figure 16. Low speed pump operation was found to provide maximum flow rates of 24.4 MGD for the existing pipeline, 27.5 MGD for Mod "A" and 31.9 MGD for Mod "B." High speed operation provided maximum flow rates of 38.1 MGD for Mod "A" and 45.3 MGD for Mod "B." In addition this pump combination has the potential to handle higher flow rates as the 42-inch pipeline is extended.

Pump operational flow range and power consumption are shown in Table 5 and Figure 17.

TABLE 2

HAZEN-WILLIAMS EQUATION

I <u>Simple Pipe</u>

$$Q = 1.318\ C\ A\ R^{.63}\ (\frac{H}{L})^{.54}$$

II <u>Complex Pipe</u>

a and b are elements in parallel
a, c, and d are elements in series

$$Q = 1.318\ C\ (\frac{H}{L*})^{.54}$$

$$L* = \frac{L_a}{(A_aR_a^{.63} + A_bR_b^{.63}/.54} + \frac{L_c}{(A_cR_c^{.63})^{1}/.54} + \frac{L_d}{(A_dR_d^{.63})^{1}/.54}$$

where:

Q = flow rate (ft^3/s)
C = Hazen-Williams coefficient
A = pipe cross sectional area (ft^2)
R = hydraulic radius (ft)
H = head loss (ft)
L = pipe length (ft)

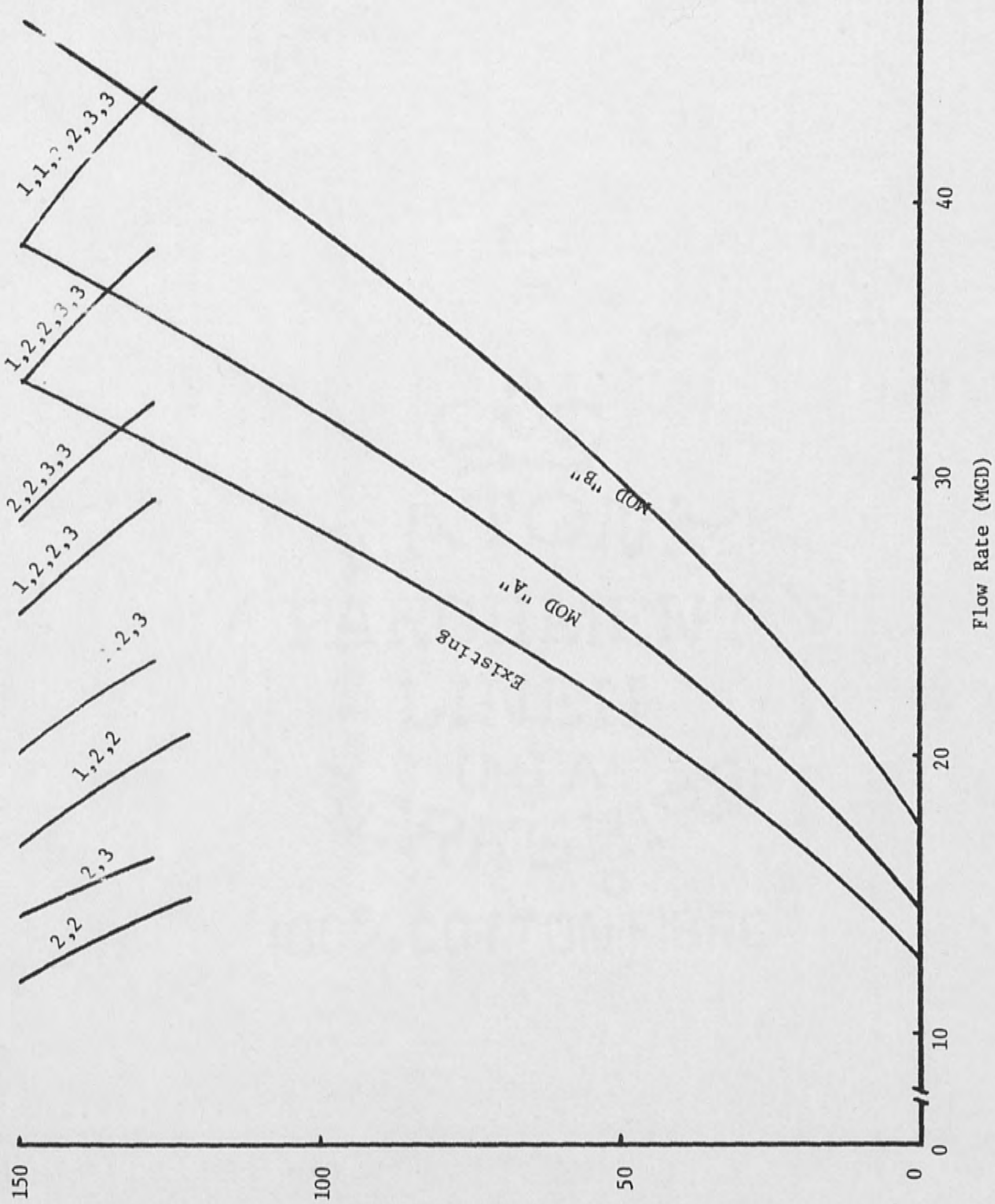

Fig. 10. System performance - option 1.

TABLE 3

PUMP CAPABILITY
Option 1

Pumps	Flow Rate (MGD) Min	Flow Rate (MGD) Max	Power (HP) Min	Power (HP) Max
1	4.9	6.8	150	165
2	5.9	7.4	180	185
3	8.3	9.2	250	245
1,1	9.8	13.6	300	330
1,2	10.8	13.3	330	345
1,3	13.2	14.9	400	400
2,2	11.8	14.8	360	370
2,3	14.2	16.3	430	430
3,3	16.6	18.4	500	490
1,1,2	15.7	19.2	480	505
1,1,3	18.1	20.6	550	555
1,2,2	16.7	20.7	510	530
1,2,3	19.1	22.0	580	585
1,3,3	21.5	24.1	650	645
2,2,3	20.1	23.4	610	615
2,3,3	22.5	25.5	680	675
1,1,2,2	21.6	26.6	660	690
1,1,2,3	24.0	27.7	730	740
1,1,3,3	26.4	29.8	800	800
1,2,2,3	25.0	29.1	760	770
1,2,3,3	27.4	31.2	830	830
2,2,3,3	28.4	32.6	860	860
1,1,2,2,3	29.9	34.8	910	925
1,1,2,3,3	32.3	36.9	980	985
1,2,2,3,3	33.3	38.3	1010	1015
1,1,2,2,3,3	38.2	44.0	1160	1170

Min. flow: Discharge head = 150 ft
Max. flow: NPSH required = 20 ft

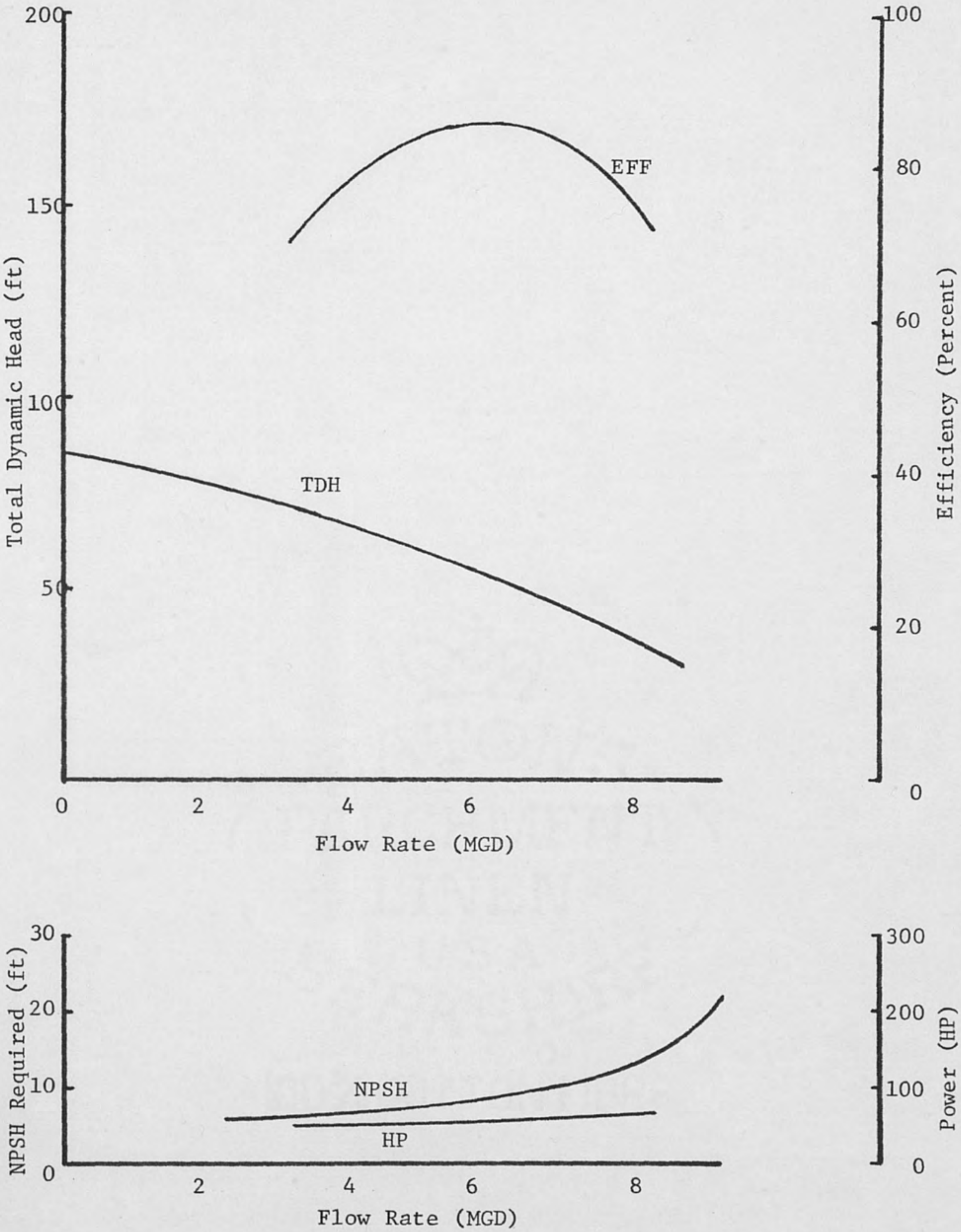

Fig. 11. Pump No. 2 performance - 1150 RPM.

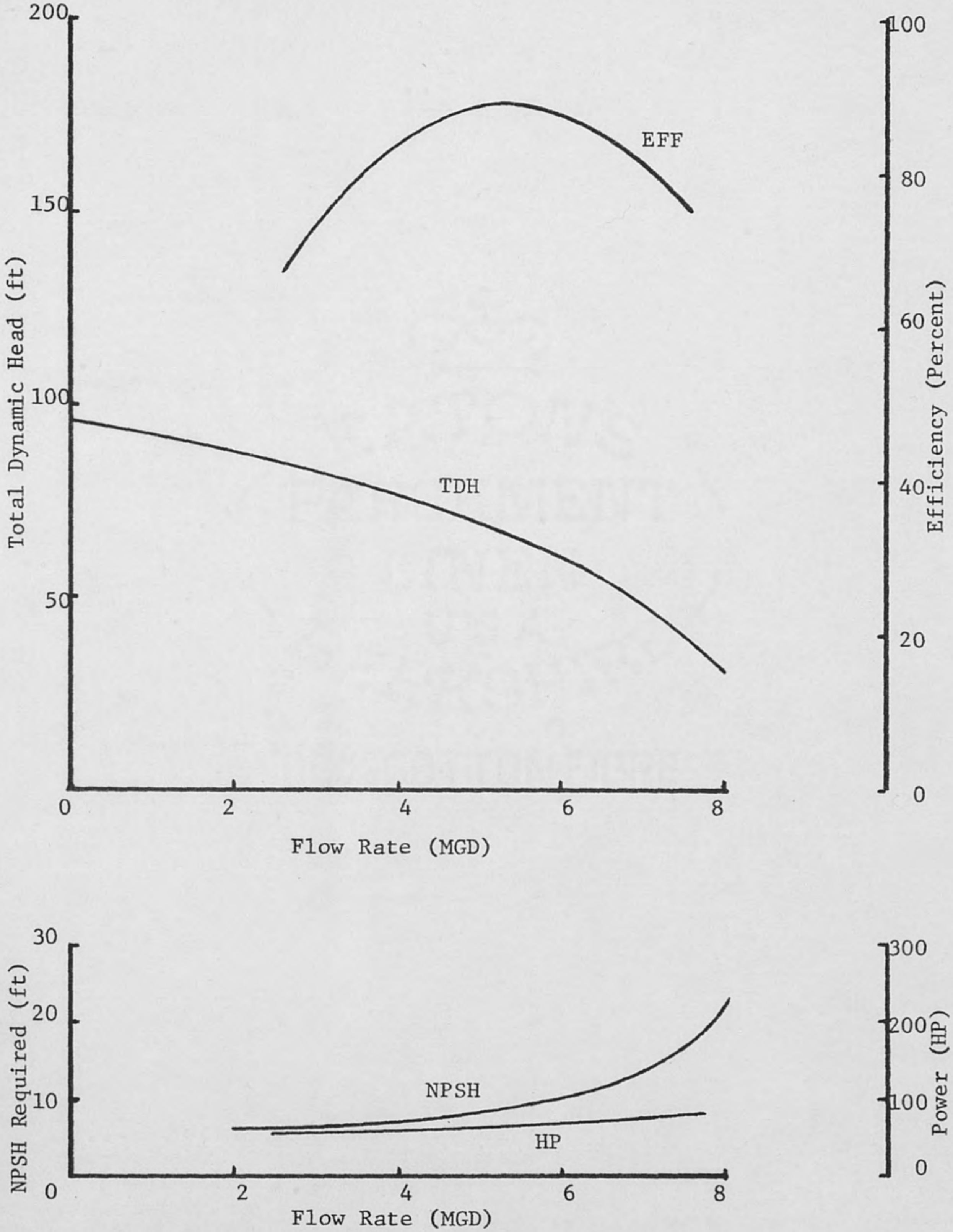

Fig. 12. Pump No. 3 performance - 1150 RPM.

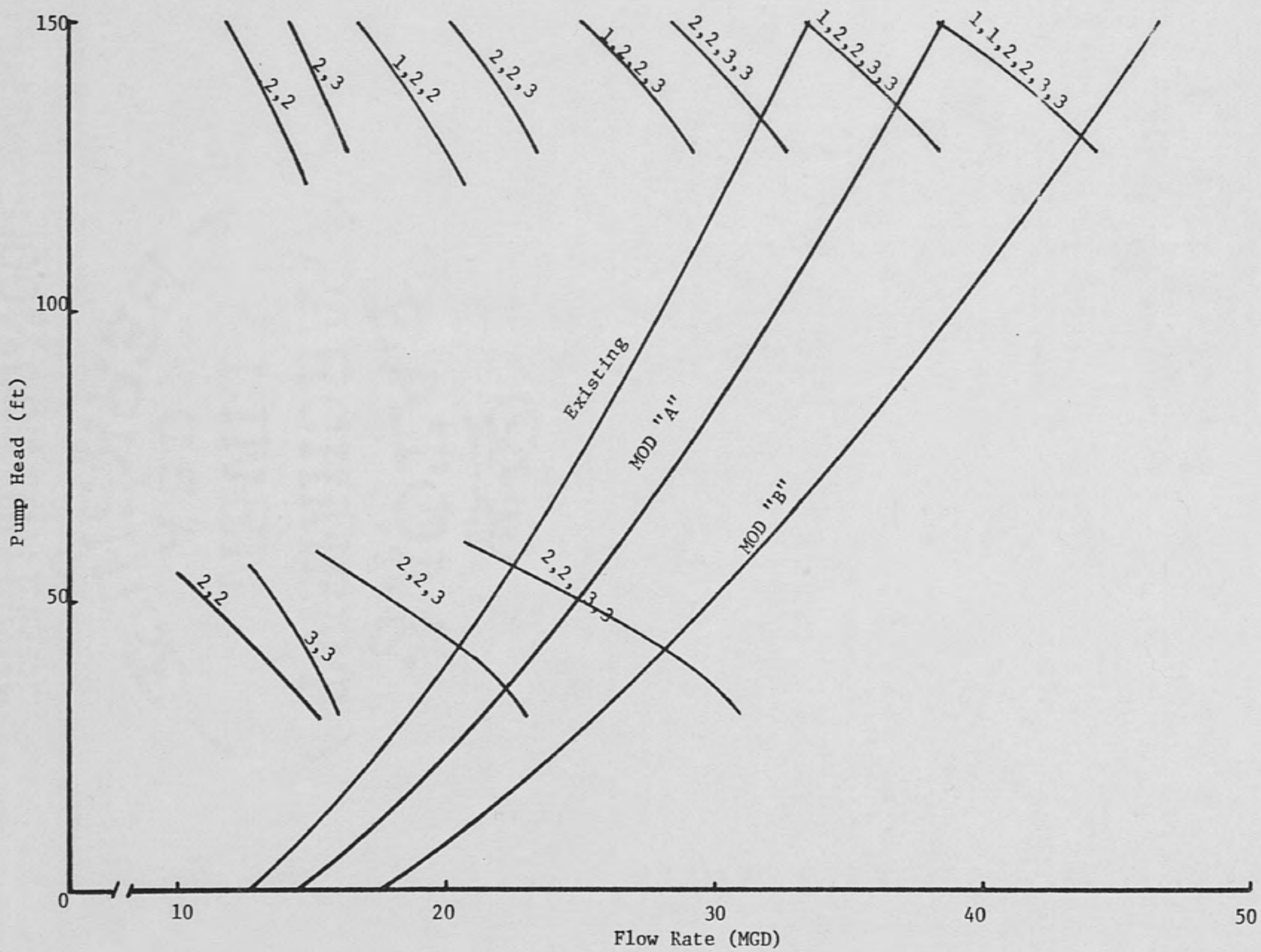

Fig. 13. System performance - option 2.

TABLE 4

PUMP CAPABILITY
Option 2

Pumps	Flow Rate* (MGD)		Power* (HP)	
2	0	7.5	48	70
3	0	8.0	50	85
2,2	0	15.0	96	140
2,3	2.5	15.5	103	155
3,3	0	16.0	100	170
2,2,3	2.5	23.0	151	225
2,3,3	5.0	23.5	158	240
2,2,3,3	5.0	31.0	206	310

* Low speed performance. For high speed performance, refer to Table 3.

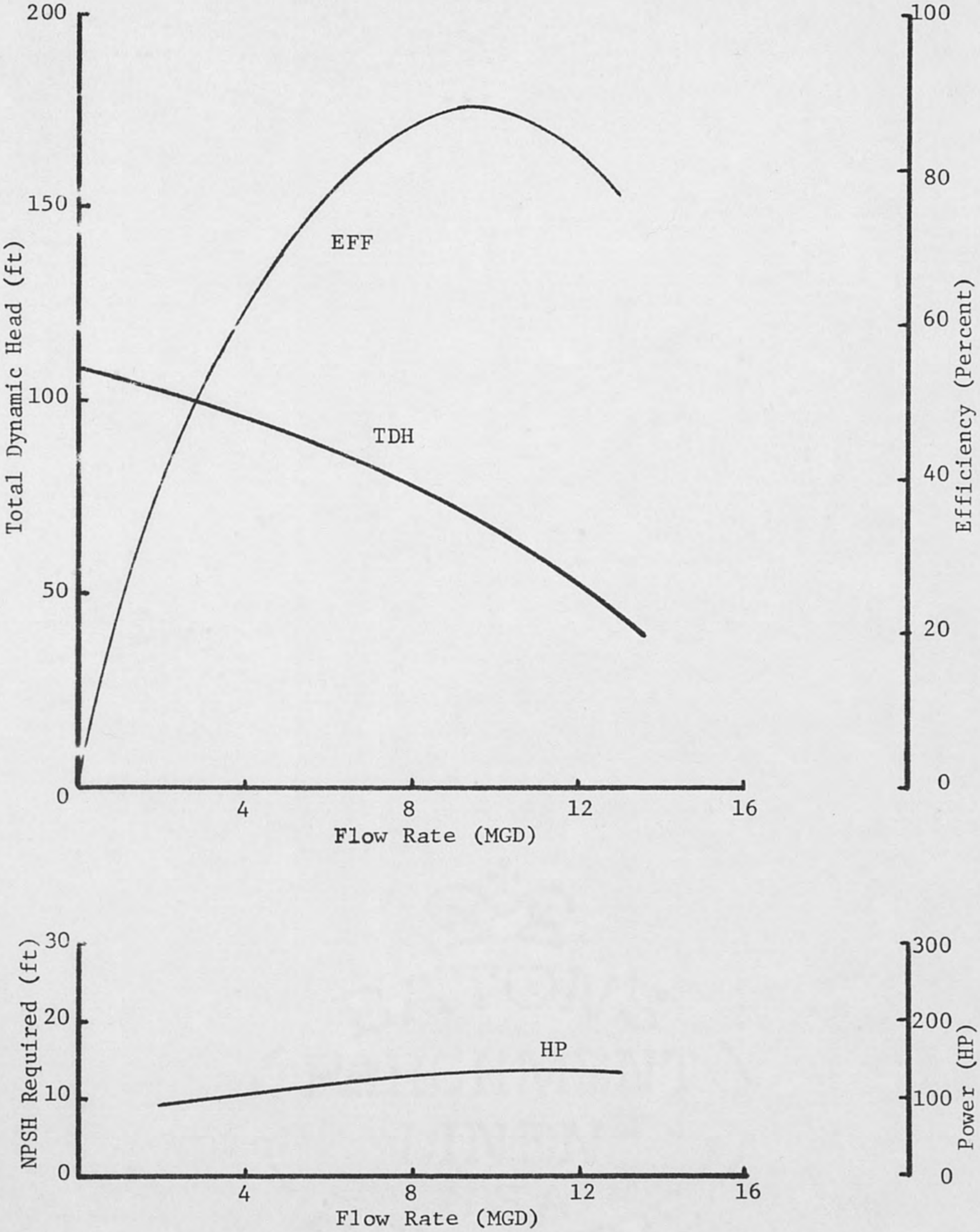

Fig. 14. Pump No. 4 performance - 860 RPM.

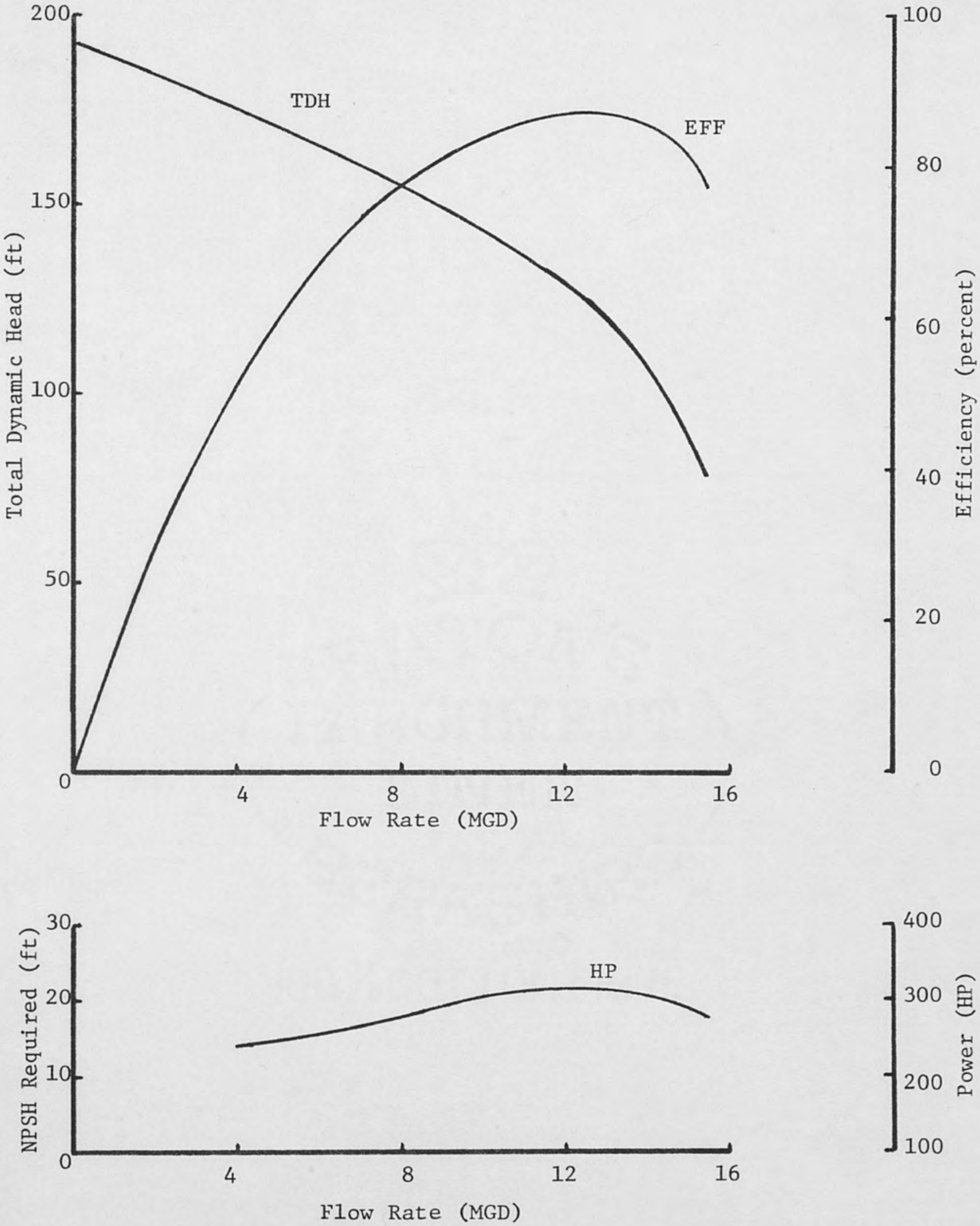

Fig. 15. Pump No. 4 performance - 1150 RPM.

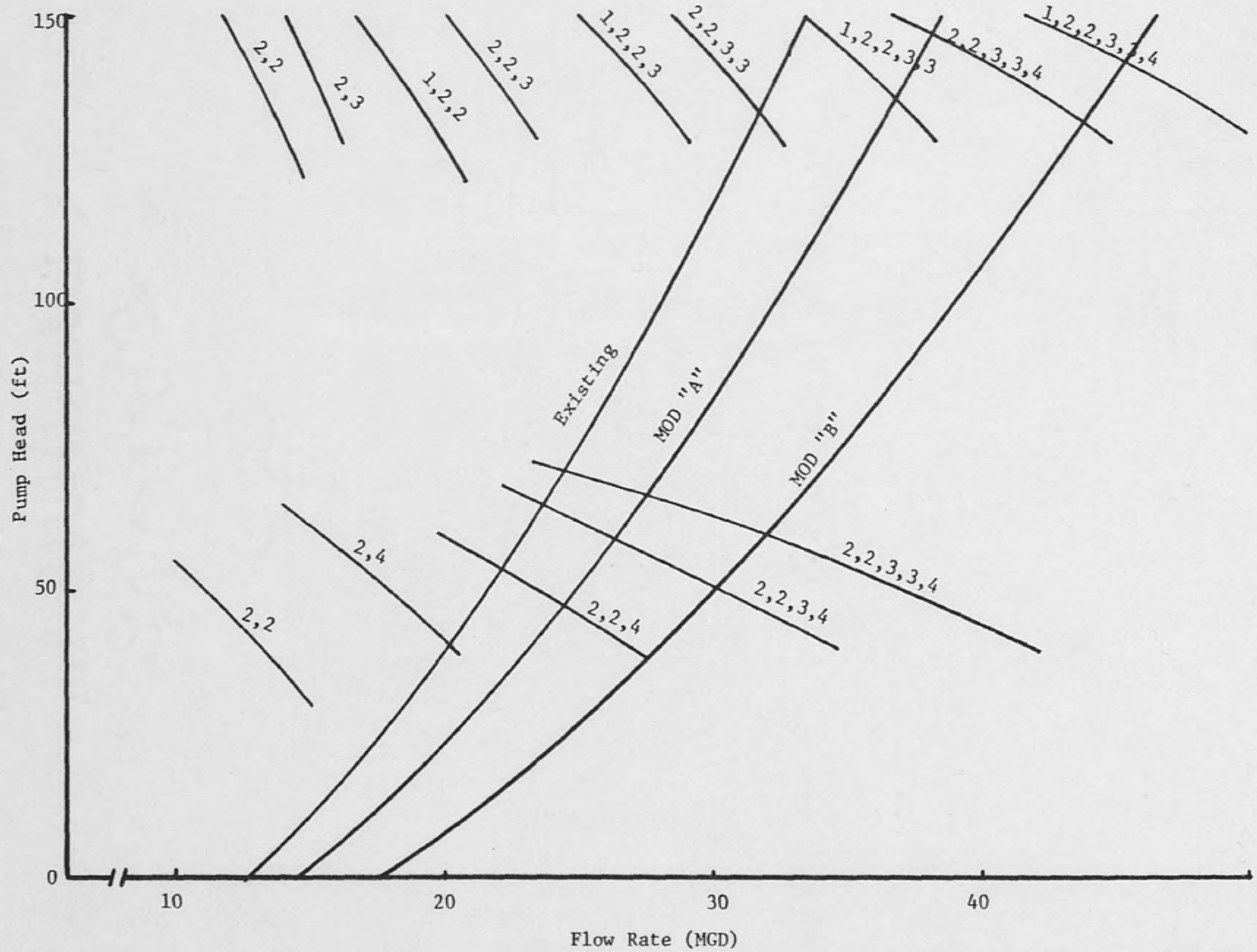

Fig. 16. System performance - option 3.

TABLE 5

PUMP CAPABILITY
Option 3

Low Speed

Pumps	Flow Rate (MGD) Min	Flow Rate (MGD) Max	Power (HP) Min	Power (HP) Max
2	0	7.5	48	70
3	0	8.0	50	85
4	0	13.5	80	135
2,2	0	15.0	96	140
2,3	2.5	15.5	103	155
2,4	6.6	20.2	173	200
3,3	0	16.0	100	170
3,4	4.2	21.0	160	215
2,2,3	2.5	23.0	151	225
2,2,4	6.6	26.9	221	265
2,3,3	5.0	23.5	158	240
2,3,4	9.1	27.7	228	280
3,3,4	4.2	28.5	210	295
2,2,3,3	5.0	31.0	206	310
2,2,3,4	9.1	34.4	276	345
2,3,3,4	11.6	35.2	283	360
2,2,3,3,4	11.6	42.0	331	425

High Speed (Partial; also refer to Table 1)

Pumps	Flow Rate (MGD) Min	Flow Rate (MGD) Max	Power (HP) Min	Power (HP) Max
1,2,2,3,4	33.7	41.3	1050	1085
1,2,3,3,4	36.1	43.4	1120	1145
2,2,3,3,4	37.0	44.8	1150	1175
1,2,2,3,3,4	41.9	50.5	1300	1330

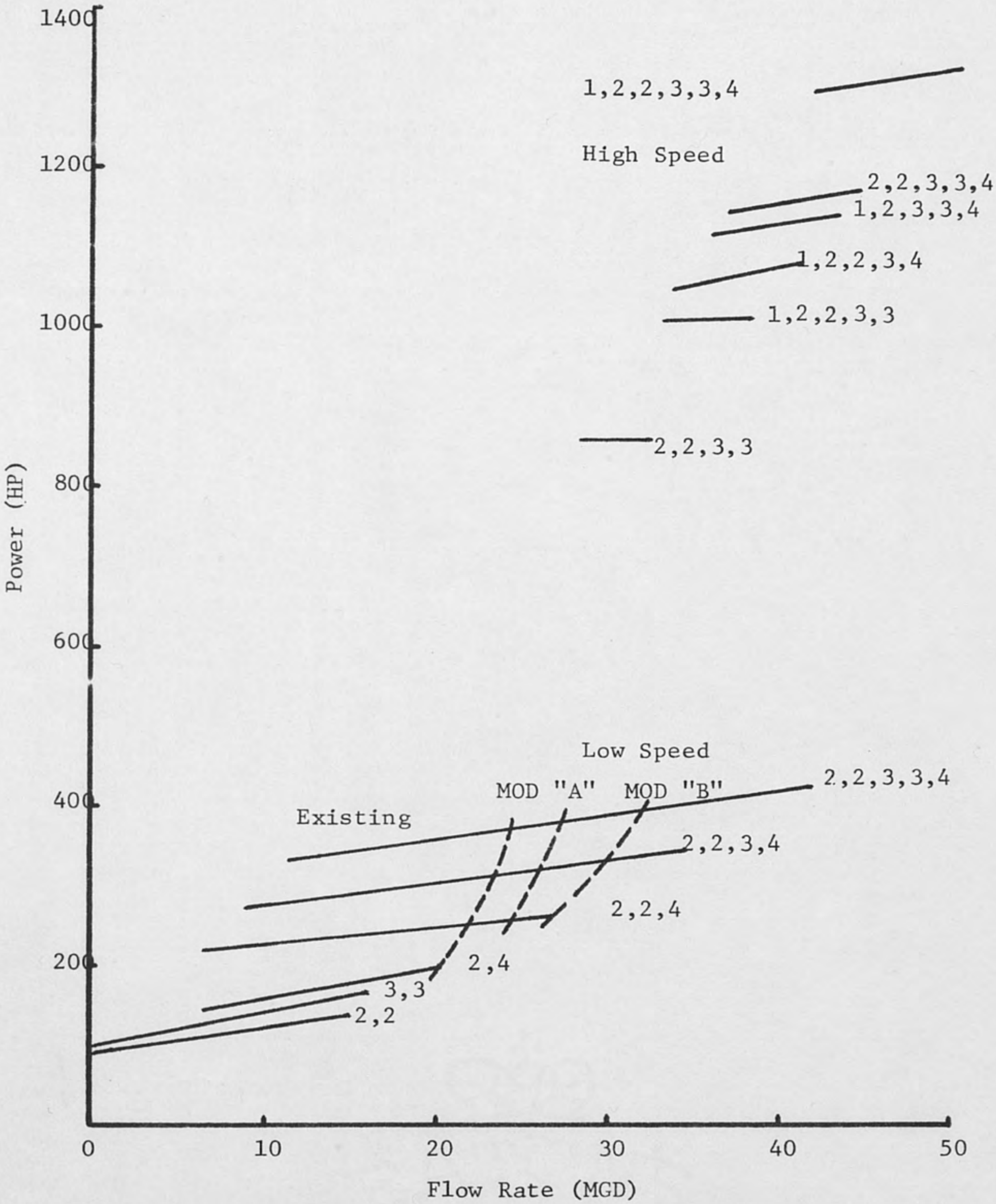

Fig. 17. Power requirements - option 3.

CONCLUSIONS AND RECOMMENDATIONS

Maximum flow rates for all of the options are summarized in Table 6. The data were compared with the projected maximum water demand shown in the introduction of this report to determine those actions required to meet the maximum daily demand through the year 2000. The following were concluded: The first 10,400-foot section of pipeline (Mod "A") should be completed no later than 1985. The second 10,400-foot section of pipeline (Mod "B") should be completed no later than 1990. Addition of either pump 1B or pump 4 (high speed) is required by 1990. Since pump 4 offers growth potential, it is the preferred solution.

The flow rates for low speed pump operation were compared with the projected average water demand. The data indicate that low speed operation of pumps 2A, 2B, 3A, 3B when combined with the pipeline modifications discussed above, was more than adequate to handle average water demand thru the year 2000. When pump 4 (low speed) was included, there was a significant increase in flow capacity above the average demand.

Power consumption for low speed operation is far less than for high speed operation at the same flow rate; however, modification to permit low speed operation requires capital investment in pumps and pipeline. An economic analysis should be performed to determine the equipment and implementation schedule which would minimize the total costs (capital plus operating and maintenance, etc.) The analysis should determine whether it is economically advantageous to speed up installation of the additional pipeline.

Another option which deserves consideration is variable speed drives for the pumps. This would allow even more efficient pumping than dual speed operation. Again, economic considerations should be the deciding factor.

The following actions are recommended:

1. Incorporate the optimized pump operation schedule presented herein.

2. Modify pumps 2A, 2B, 3A, and 3B for dual speed operation as soon as possible (cost $50,000). All costs are in 1982 dollars.

3. Add 10,400 feet of 42-inch pipe to be completed no later than 1985 (cost $800,000).

4. Add a large capacity, dual speed pump and mount in the present location of pump 1B (cost $120,000).

5. Add 10,400 feet of 42-inch pipe to be completed no later than 1990 (cost $800,000).

6. Perform an economic analysis to determine the equipment and implementation schedule which would minimize total costs. Results of the analysis should be used to modify the above recommendations.

7. Investigate the use of stored water to smooth the flow demands placed on the pumps.

TABLE 6

MAXIMUM FLOW RATE (MGD)

Transport System	Pump System (Low Speed/High Speed): Existing	Option 1	Option 2	Option 3
Existing	- / 33.3	- / 33.3	22.4 / 33.3	24.4 / 33.3
Mod A	- / 36.7	- / 38.3	24.8 / 38.3	27.5 / 38.1
Mod B	- / 38.3	- / 43.6	28.1 / 43.6	31.9 / 45.3

Existing: 1A, 2A, 2B, 3A, 3B single speed
Option 1: 1A, 1B, 2A, 2B, 3A, 3B single speed
Option 2: 1A, 1B single speed. 2A, 2B, 3A, 3B dual speed
Option 3: 1A single speed. 2A, 2B, 3A, 3B, 4 dual speed

APPENDIX

APPENDIX

Example 1. Suction Head Loss Calculation

For the steady state situation, the flow from tanks A and C would be zero. For a worst case situation, assume that half of the flow passes through tank B and travels 240 feet to the pumps, and half of the flow passes through tank D and travels 100 feet to the pumps. Then the maximum suction head loss is 4 feet.

$$Q = 1.318\ C\ A\ R^{.63} \left(\frac{H}{L}\right)^{.54}$$

where:

Q = 22 MGD (34 ft^3/s)	flow rate
A = 3.14 ft^2	pipe area
R = 0.5 ft	hydraulic radius
L = 240 ft	pipe length
C = 120	H-W coefficient

Example 2. NPSH Calculation

$$NPSH = H_{ap} + H_z - H_f - H_v - H_{vp}$$

where:

H_{ap} = 30 ft (13 psi)	atmospheric pressure
H_z = 10 ft	elevation
H_f = 4 ft	pipe loss
H_v = 2 ft	velocity head
H_{vp} = 1 ft	vapor pressure

Then the available NPSH = 33 ft.

Example 3. Wasted Power Calculation

$$P_w = \frac{P_p}{N_m} \times \frac{H_w}{H_d}$$

where:

P_p = 525 HP for 1A, 2A, 2B — pump power (Figure 9)
N_m = .85 — motor efficiency
H_w = 87 ft — wasted head (Figure 8)
H_d = 128 ft — discharge head (Figure 8)

Then the wasted power, P_w = 420 HP.

Example 4. Power Cost Calculation

Cost = (1 HP) (.746 KW/HP) (24 hr) (.06 $/KWH)

Then the cost = $1.07 per horsepower-day.

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